IMPACTS OF HEAVY AXLE LOADS ON LIGHT DENSITY LINES IN THE STATE OF WASHINGTON

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Planning and Programming Service Center

Impacts of Heavy Axle Loads on Light Density Lines in the State of Washington

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16. ABSTRACT

The overall purpose of this report was to determine how shippers and shortline railroads are impacted by the use of heavy cars (286,000 lb) on branch lines with light rail or deferred tie maintenance. Specific objectives were to determine how shippers were handling the problem, the need for investment in trackage and the magnitude of that investment to sustain viability of shortline railroads and branch lines in Washington State.

Even with innovative short run solutions, investment in upgrading trackage appears to be the only long-term solution. Approximately 480 miles need to be upgraded to effectively handle 280,000-pound carloads. It will cost $250,000-300,000 per mile to upgrade inadequate branch lines. The cost for the state of Washington is from $110 to $141 million; not including bridge rehabilitation; if lines aren't upgraded, many of them may be abandoned and the economic benefits of the larger railcars are lost to shippers.

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Executive Summary

A transition to heavier rail cars has been underway in the United States for some time. In the 1970s, much of the branch-line network was restricted to gross car weights of 220,000 pounds. Today, most Class I mainlines allow 286,000-pound cars with net loads of 110 to 115 tons. And, all recent new car purchases are at the higher weight.

The 286,000-pound cars are very economical. However, they pose problems for short line railroads and branch lines. The branch-line network was designed decades ago in an era of relatively light car weights. Much of the track is built with light rail weighing 90 pounds per yard or less. Some short line segments have thin ballast sections and defective crossties. See Figure 1 for existing Washington rail lines.

Short line railroads must be able to handle heavier cars in interchange service in order to remain viable in the future. If branch lines are abandoned, shipping costs will increase. In addition, highway maintenance costs will increase as traffic is shifted from railroads to heavy trucks.

What is the purpose of this report?

Many studies have examined the benefits and costs of using heavy rail cars on mainline routes. However, these studies reflect movements over heavy rail. They are not applicable to branch lines with light rail or deferred tie maintenance. Further, little information has been developed on how shippers and short line railroads are impacted by this situation. In comparison, this study focuses on the effects of heavy cars on branch-line tracks and the alternatives available to shippers. It addresses several key questions, including:

- How are shippers attempting to handle this and other transportation concerns?
- How will existing branch lines in Washington State perform under 286,000-pound carloads?
- What rail weights and maintenance levels are needed to ensure long-run performance under heavier axle loads?
- What track rehabilitation or upgrading costs are necessary to maintain the viability of short line railroads and branch lines in Washington State?

How is track performance measured in this study?

As a heavy car moves over a line, the track is compressed temporarily or *deflects*, and then rebounds after the load has been removed. Vertical deflection is the best single indicator of track strength, life, and quality. The up-and-down pumping action of the track under repeated wheel loads is a primary source of track deterioration. The American Railway Engineering and Maintenance Association recommends a maximum deflection of one-quarter inch. Track that deflects .40 inches or more will deteriorate quickly under heavy axle loads.

In this study, track deflections under 286,000-pound carloads are simulated for several types of light-rail sections and different combinations of track support. The performance of heavier rail also is simulated. The results are used to decide when tracks need to be upgraded and the minimum rail weights that are needed for long-term performance under heavy axle loads.

What are the key findings of the report?

Even with innovative short run solutions, investment in upgrading trackage appears to be the only long-term solution.

The grain industry, due to low product prices, government programs and innovative rail programs, has survived the current capacity shortages. The Grain Train program, combined with shuttle train efficiencies and loading only at 198,000 pounds has momentarily provided service and needed capacity. Seasonal shortages and rate increases are expected in the future.

The unused capacity of the 286,000-pound car could provide efficiencies and services not now available to shippers. Investment in infrastructure necessary to utilize this available capacity is critical to the shipper and short line railroads. Continued utilization of the railroads offers energy and road maintenance savings to both private and public stakeholders.

Light-rail sections will not perform adequately under heavy axle loads unless trains are restricted to very slow speeds

Rail weight, overall track support, and train speed are important factors in track performance. Very light rail sections (e.g., 70 pounds per yard) aren't likely to perform satisfactorily under heavy axle loads. With good tie maintenance, good ballast, and slow speed operations, 90-pound rail *may* perform satisfactorily under 286,000-pound carloads. However, deferred maintenance or higher-speed operations will increase deflection to unacceptable levels. In comparison, 112-pound rail with average track support exhibits good performance at speeds of 40 mph.

The simulations suggest that it's desirable for railroads to upgrade track built with lighter rail (e.g., less than 90 pounds per yard). Moreover, when upgrading track, it's desirable to use heavier rail (e.g., 112-pound or 115-pound rail) instead of relaying track with used 90-pound rail.

What actions are recommended?

- All track built with less than 90-pound rail should be upgraded
- Unless a track has excellent support and tie maintenance, 90-pound rail sections should be upgraded so that branch lines can be operated at cost-effective speeds (e.g., at least 25 mph)
- Jointed 90-pound rail that remains in service should be welded into longer sections to dampen dynamic effects and provide for more continuous support

How many miles of branch line need to be upgraded?

There are more than 1500 miles of branch line or short line railroad in Washington State. Approximately 480 miles of these lines will need to be upgraded to effectively handle 286,000-pound carloads.

How much will it cost per mile to upgrade these lines?

The cost to upgrade a rail line is very dependent upon its unique circumstances. In general, it will cost $250,000 to $300,000 per mile to upgrade inadequate branch lines, exclusive of bridge rehabilitation costs. This cost range is very similar to estimates developed in a recent study of branch lines in Iowa. In that study, the Iowa Department of Transportation estimated that it would cost $262,000 a mile to upgrade branch lines to effectively handle 286,000-pound rail cars.

How much will it cost to rehabilitate branch lines in Washington?

At the low end of the range, the estimated cost to rehabilitate 482 miles of line is $117 million. At the high end of the range, the estimated cost is approximately $141 million. These estimates do not reflect any bridge rehabilitation work, and some bridgework almost certainly will be needed. Moreover, they reflect the price of second-hand rails and limited replacement of crossties. For these reasons, the estimates are presented as *minimum* rehabilitation costs.

What will happen if the lines are not upgraded?

If branch lines can't handle heavy cars effectively, they will become obsolete. In the future, many of them may be abandoned.

Each year, more than 150,000 carloads of freight are originated or terminated on branch lines in Washington State. Approximately 600,000 additional truck trips per year would be needed to transport this freight.

Truck movements to and from branch-line stations travel over local arterial and collector highways. These secondary highways are not designed to the same standards as interstate or principal arterial highways. Consequently, highway maintenance costs will increase if branch lines are abandoned. If rail lines are abandoned, farmers, businesses, and communities will be left with fewer shipping options and may have to pay higher freight rates.

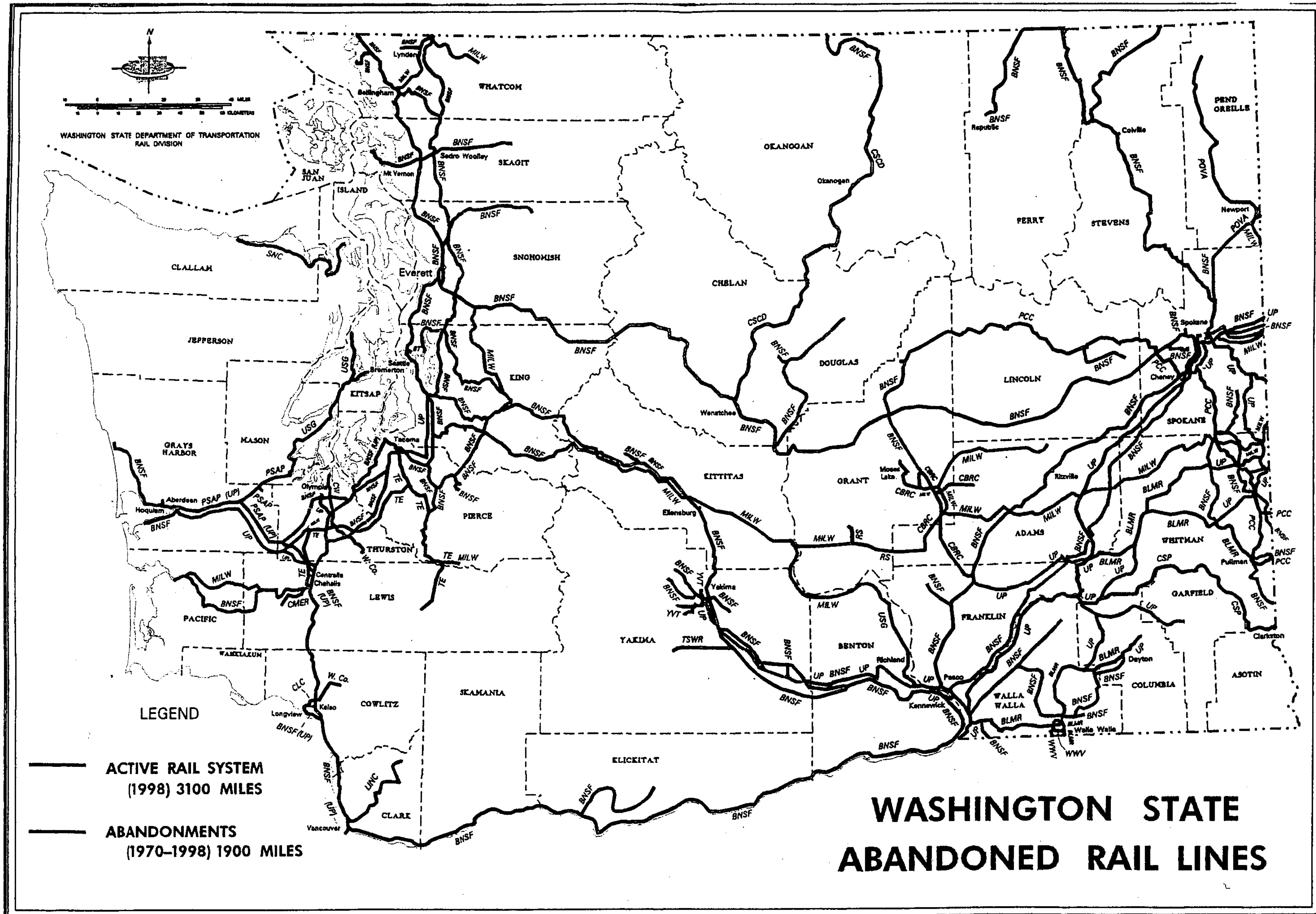
New possible car fleet capacity, to offset chronic car supply shortages, will be lost if the heavy cars cannot be loaded fully.

Background of Issue

The transition to heavier rail cars has been underway in the United States for some time. In the 1970's, much of the branch-line network was restricted to gross car weights of 220,000 pounds (which allowed net loads of 70 to 80 tons). However, the need for effective utilization of 100-ton hopper cars resulted in branch-line capacity limits being raised to 263,000 pounds. Today, most Class I railroad main lines allow 286,000-pound cars with net loads of 111 tons or greater. Most car purchases by Class I railroads have been of 286,000-pound cars in last 10-15 years.

Larger rail cars offer many cost savings to mainline railroads because of their higher net weight-to-tare weight ratios.[1] Higher net-to-tare weight ratios reduce the annual car miles required to haul a given tonnage, and thus reduce car ownership costs per tone. A higher net-to-tare ratio also reduce the number of axles required to haul an equivalent train weight, and thus reduces train resistance and fuel cost per ton-mile.[2] Finally, larger cars used in unit train service reduce labor costs per ton-mile because of a given train length is comprised of more revenue tons. If these cost efficiencies are transferred into rate reduction, shippers as well are directly benefited. However, the economic benefits of larger cars should be weighed against the increased equipment and track maintenance costs that will result from their use.

In a 1990 study, BN concluded that the 286,000-pound car loaded to 112 tons was the optimal car weight for a hypothetical western coal route. At this load, the annualized estimated cost savings were about 5.2 percent. However, BN cautioned that the results of the coal corridor study should not be generalized to other corridors or routes and that "heavy axle loads shorten track component lives, increase the rate of degradation of the track structure, and increase the costs of derailments."[3] BN suggested that "the key question in evaluating the overall costs and benefits of heavy axle-loading equipment is whether these operating cost savings do, in fact, offset the increased track and equipment costs from increasing axle loads."[4]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LEGEND
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ABANDONMENTS (1970–1998) 1900 MILES
WASHINGTON STATE DEPARTMENT OF TRANSPORTATION
RAIL DIVISION
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WHATCOM
SKAGIT
SAN JUAN
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CLALLAM
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KITSAP
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GRAYS HARBOR
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THURSTON
PACIFIC
LEWIS
WAHKIAKUM
COWLITZ
SKAMANIA
CLARK
OKANOGAN
CHELAN
DOUGLAS
KITTITAS
YAKIMA
KLICKITAT
FERRY
STEVENS
PEND OREILLE
LINCOLN
SPOKANE
GRANT
ADAMS
WHITMAN
BENTON
FRANKLIN
WALLA WALLA
COLUMBIA
GARFIELD
ASOTIN
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Yakima
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Republic
BNSF
UP
MILW
PCC
POVA
CSCD
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PSAP (UP)
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CW
CMER
W. Co.
CLC
LINC
BNSF (UP)
YVT
TSWR
RS
CBRC
BLMR
CSP
WWV

System-wide use of 286,000-pound cars would require travel over branch lines and short line networks. Washington has an extensive array of abandoned and short line railroads (Figure 1). These tracks are not built to the same standards as Class I railroad mainlines. Moreover, many of them have suffered from deferred maintenance. In 1989, FRA concluded that the track rehabilitation needs of local and regional railroads averaged $27,400 per mile or $208 per car. However, the rehabilitation needs average $755 per car for railroads with traffic densities of 21-to-40 carloads per mile and $3,248 per car for railroads in the lowest density class (less than 20 carloads per mile).

The Association of American Railroads had conducted a series of heavy axle load (HAL) tests during the last 15 years. AAR concluded that 125-ton cars could be accommodated by a standard mainline track structure. However, the cost of maintaining the track would increase by about 30 percent. In a later phase of the studies, AAR analyzed the use of cars with improved suspension systems on a hypothetical 80 million gross per ton western coal route. For this scenario, AAR estimated a 6.6 percent net savings per ton-mile for the 286,000-pound car versus a 2.2 percent net savings for the 315,000-pound car. The savings were computed in relation to a 263,000-pound car with improved suspension trucks.

Yet, much of the gathering and local movements occur on light density or short line railroads. Thirty percent of the trackage in the nation is now operated by these short line railroads, mostly on light-density lines. The revenue on these lines is about 20% per track-mile of the revenue of the large Class I railroads. At the same time the costs for short line railroads are slightly lower due to different work rules, lower track specifications and 2nd hand track materials. These railroads survive by providing a high quality of service to their customers and linkage/access to shippers' markets via Class I Railroads.

These short line tracks were designed decades ago in an era of lighter car weights, often using 70-90 pounds per yard rail. Also the older lines often have thin ballast sections, weak bridges and deteriorated cross ties. The heavy axle cars exacerbate this deferred maintenance, caused by financial constraints of short line railroads.

These conditions point towards either an inability to handle these heavier cars desired by the Class I railroads or need for a substantial capital investment in these light density lines. Even as the short lines attempt to use lower speeds and patchwork rehabilitation in the short run to survive and service their customers, the long run problem exists.

Study Purpose and Objectives

The general purpose of the project is to study the potential impacts of heavier cars on light-density track and short line railroads in Washington and provide information for planning and investment purposes. Specific objectives of the study are to:

1. Assess the likelihood of heavier cars being used on Washington branch lines and short line railroads in the future and how shippers and short line railroads are reacting to this change.
2. Evaluate the expected long-run performance of different types of light-density track sections under heavier carloads.
3. Define the combinations of minimum rail weights, track support, and maintenance standards (e.g., percentage of good ties and ballast depths) needed to meet light-density track performance goals under heavier carloads and differing speeds.
4. Estimate capital investment needs associated with upgrading light-density rail lines to effectively accommodate heavier cars.
5. Estimate potential impacts to railroads, shippers, and the State if lines are not upgraded and identify relevant issues for research and policy development.

Methodology and Study Approach

The overall study approach was two pronged, a technical evaluation and an empirical market analysis. Determining the likely future and structure of use of heavy cars on branch lines was undertaken by a survey of major shippers and short line railroads, principally but not exclusively in eastern Washington. The results of this shipper survey (see Appendix III) generates a broad understanding of how the heavy cars are currently affecting the shipping industry, how the shippers and short lines are handling these impacts in the short run and, from their perspective, what are the alternatives for the future. The results of the survey and interviews were then used with other railroad and grain-marketing data in determining the overall industry response to the heavy cars.

The technical analysis for the study was conducted using railroad track models. As a heavy car moves over a line, the track is temporarily compressed or "deflects", and then recovers after the load has been removed. The up and down track movement under repeated wheel loads is a primary source of track deterioration. Railroad track models were used to simulate track deflections under varying loads, speeds and track conditions. The technical Appendix I details this analysis.

A survey of Washington short line railroad and other light density lines (Appendix II) was done by a combination of a mail questionnaire and a follow-up telephone survey (Appendix IV). BNSF provided track charts for Class I branch lines. These conditions, combined with the simulations, produced a list of line segments that may need upgrading. From this total list it was possible to determine the investments needed in Washington state to handle the heavy rail cars.

Shipper and Short Line Impacts

Existing Situation

The existing agricultural situation has lessened, at least temporarily, the traditional chronic car shortage. The advent and growth of the Grain Train program, combined with slightly decreased shipment volume due to the Conservation Reserve Program (CRP), has been used judiciously by the region's shippers and short line railroads. Additionally, the low price differential for wheat and other grains has caused the Loan Deficiency Payments (LDP) to be commonly used by growers and shippers. Since this abstracts shipper price from any short-term changes in the market price, the result has been a more orderly movement of volume throughout the year, with fewer peaks of car demand. However, as prices recover in the crops industry the seasonal shortages are expected to once again become a problem.

Shippers and short lines have combined to expect and produce loads of a maximum of 198,000 pounds, to eliminate derailing and track damage. This rural standard, about 100 tons, is met guide well by shippers who are experienced in estimating such loads, if a scale isn't available, especially since the Class I railroads in the state will impose a penalty and mandate unloading if overloading is noticed.

Grain elevators thus far are still ordering C-6 cars (100 ton) and often get C-6X (110 ton). When this happens they pay at the C-6 rate, load only to the 198,000 agreed upon maximum weight and ship to tidewater terminals. Managers are concerned about how long this payment at the lower level will be allowed by the Class I railroads and also see the unused weight as lost opportunity to increase the effective capacity of the existing car fleet.

The major shortline railroad has 410 miles of light density lines, bought or leased from the Union Pacific (UP) and/or the Burlington Northern Santa Fe (BNSF). The line is mostly 70-80 pound rail while, as indicated in the technical section of this report, 115 and 133 pound rail is desired and generates the desired performance standards. In addition, this railroad also has about 350-400 bridges on its trackage, many of which are expected to be impacted by the heavier cars. Current speed on these lines is 25 mph with some sections as slow as 10 mph, contrasted to the desired 40 mph of most short line railroads.

Shippers are clear in their preference for continued use of railroads as the preferred mode of choice. The current 26-car configuration allows 85,000 bushels to be moved in one, fairly flawless, movement from the elevator, in contrast to the multiple truckloads and loadings necessary in a truck-barge movement. Payment for the product is now very similar (railroad to take longer), with a 90% payment upon shipping.

The rate structure among the alternatives available for shipping is quite close and shippers are quite responsive (elastic demand) to changes in rates charged. One major shipment pattern currently has rates of 32¢ per bushel in a 26-car train-movement, 36¢ for a 3-car shuttle to the barge on the river and 40¢ for the traditional truck movement to barge. Hence, any increase is cost (rate) to the shipper in the rail mode may generate significant traffic shifts from both the short line gathering railroad and the Class I railroad.

Another relevant concern for the short line railroad arises from their method of payment by the Class I railroads. The short line railroads are paid on a per car basis by the Class I so, if cars are loaded to the 110 ton capacity, the short line railroad effectively loses 10% of their revenue producing traffic, even while the heavier cars cause increased costs to that railroad. Shortline railroads have initiated negotiations for a higher per car payment at the heavier carload; such an increased payment to the short line railroad can be expected to appear as an increased rate to the shipper.

Shipper alternatives

Shippers have been very active in working to develop solutions to the existing transportation problems. Working with the state of Washington, the Grain Train program, which uses refurbished 100-ton cars, now can be used, for at least a selected volume, to move grain to Portland and other markets. Such older, lower weight cars offer at least a partial, but probably temporary, solution.

Another alternative is the concept of "shuttle trains", now used in southeastern Washington. This is unlike the concept used in the Midwest to long distance western markets where trains are moved as a unit, returning back to the origin area. Washington's shuttle trains, developed by a partnership of port, railroad, barge and shipping elevators, drops off a given number of cars (port and railroad owned) at each location on a line, returning that day or so to put them together and shuttle them to the river in an innovative rail-barge movement. The use of this concept is spreading and is particularly useful for some of the emerging specialty crops in the region.

The third alternative is increased use of the truck-barge movement with direct shipments to the river. Shippers worry about the increased rates, the loss of past investment in rail loading facilities, new required truck loading investment and the condition of roads and bridges between the river and their elevator. Yet, new transfer elevator capacity has been and is being developed at the river to service such new demand, if it ultimately materializes.

A further alternative is simply to maintain the status quo, meaning to load light at 198,000 pounds. If rates are increased corresponding to the 110-ton capacity it can become an effective 10 percent increase. Shippers, shortline and Class I railroads are actively looking at the issue of funding sources and investment arrangements to maintain the existing level of service. Industry members expect some rationalization (abandonment) of some light density lines and, in the worst scenario, a loss of economic viability for some short line railroads under this alternative.

Issues

It is evident that shippers and short line railroads have been innovative in dealing with the issues of heavy cars and overall car capacity. Thus far, rail rates have not been raised to the expected level. However, the alternatives are, at least, only short run fixes; long run solutions are based on investment in light density lines to capture, for the shipper and the railroad, the economics offered by the heavy cars. As such investment occurs, the quality of the track and attendant quality of service increases the economic viability of the railroads, maintaining or even enhancing the role of these lines in rural economic development.

The short-term use of shuttle trains has succeeded in keeping some traffic off of the state and local roads. However, movement to the truck mode entails damage and deterioration of rural and state roads as increased volume, sometimes in wet conditions, occurs. Shippers are very sensitive to the impact on their local community of their trucks moving over local roads; counties and the state are faced with increased highway maintenance and reconstruction as a result of the new traffic. Rebuilding the light density loads to handle the heavier cars is an effective 10% increase in car capacity, improving the perennial problem of chronic car supply shortage in this industry.

Creative partnerships have been developed in the short run by shippers, ports, railroads and barges. Such creative investment funding alternatives seem to be desired by the industry members as a long-term solution is developed. The impact of recent and future energy costs may well be the instigator of new financing arrangements.

Investment Needs for Washington State Short Line Railroads

The basic findings of the technical analysis are that significant improvements in light-rail sections are needed unless very slow speeds are acceptable. Such speeds are generally uneconomic to shippers and the railroads. Appendix I contains the technical equations and simulations used in the analysis. The focus of the analysis was on what performance could be expected, what magnitude of investment per mile would be needed to bring typical light lines up to acceptable standards, avoiding the many impacts detailed in the previous industry section. Particular and detailed attention was paid to track components, speed, tie maintenance and deflection as it affected track performance. Then the survey of Washington short lines produced the current conditions of trackage in the state. The final outcome is a precise determination of track rehabilitation needs.

The track models and desired performance standards result in a need to upgrade any track with less than 90-pound rail, combining support and tie maintenance to achieve 25 mph speed. The existing 90-pound rail should be welded into longer sections to dampen dynamic effects and increase overall support.

It was found that approximately 480 miles of these lines, of a total of more than 1,500 miles in the state, will need to be upgraded to effectively handle the new 286,000 pound car loads (see survey results in Appendix I). At a determined cost of $250,000-$300,000 per mile on average (this funding corresponds closely with estimates in other states, other studies and in specific interviews with short line operators in Washington), to upgrade Washington's lines needing repairs generates a cost of $117 million to $141 million. What is unsettling is that these estimates do not include any bridge upgrading costs, and some bridgework will almost certainly be needed. These estimates (Appendix I) are most certainly a minimum estimate of rehabilitation costs. The step-by-step analytical process detailed in Appendix I reveals the conservative assumptions used and the overall cautionary approach to the analysis.

Endnotes

[1] For example, a 263,000 pound covered hopper car (loaded to 100 tons) has a net-to-tare weight ratio of 3.19, whereas a 286,000-pound car (loaded to 111 tons) has a net-to-tare weight ratio of 3.47. Thus, when used in 100-car train service, the 286,000 pound car increases train payload capacity by 11,000 tons (which is equivalent to an additional eleven 100-ton covered hopper cars).

[2] "BN Big Car Economics," *Railway Age,* April 1990.

[3] Ibid.

[4] Ibid.

[5] A "kip" is a kilo-pound or one thousand pounds.

[6] Railroads have increased the diameters of car wheels in an effort to increase the contact area with the rail and thereby reduce contact stress.

[7] As used in this study, the term "branch line" includes short-line railroad tracks, as well as Class I branch lines that are built with light rails.

[8] A telephone survey of short-line railroads was conducted during this project. As part of the survey, railroads were asked to describe tie and ballast conditions on their lines.

[9] American Short-Line and Regional Railroad Association and Upper Great Plains Transportation Institute, *1998 Annual Data Profile of the American Short-Line & Regional Railroad Industry*, December, 2000.

[10] For example, a 263,000 pound covered hopper car (loaded to 100 tons) has a net-to-tare weight ratio of 3.19, whereas a 286,000-pound car (loaded to 111 tons) has a net-to-tare weight ratio of 3.47. Thus, when used in 100-car train service, the 286,000 pound car increases train payload capacity by 11,000 tons (which is equivalent to an additional eleven 100-ton covered hopper cars).

[11] "BN Big Car Economics", *Railway Age*, April 1990.

[12] Kalay, Semih and T. Guins. "Heavy Axle Loads: The Dollars and Sense Case," in *Railway Age*, March 1998.

[13] Kalay, Semih and T. Guins. "Heavy Axle Loads: The Dollars and Sense Case," in *Railway Age*, March 1998.

[14] Kalay, Semih and T. Guins. "Heavy Axle Loads: The Dollars and Sense Case," in *Railway Age*, March 1998.

[15] Kalay, Semih and T. Guins. "Heavy Axle Loads: The Dollars and Sense Case," in *Railway Age*, March 1998.

[16] Ahlf, Robert E. "The Implications of the 100-Ton Car", *Modern Railroads*, February 1980.

[17] His reasoning, in part, was that deployment of 100-ton cars changed the limiting factor in rail life from wear to fatigue-related defects, as discussed in the following passage: *Rail head contact stresses, previously of minor importance in determining rail life, are now the dominant factor. These stresses, beyond the elastic limit, are resulting in rapid propagation of fatigue-related defects, which are becoming the primary limitation on rail life in tangent track. Depending upon the defect rate, which a railroad is willing to live with, tangent rail life is being reduced to less than one-half of what it would otherwise be with lighter cars.*

[18] This net cost assumes that the freight cars averaged 200 miles per day.

[19] Kalay, Semih and Albert Reinschmidt. "An Overview of the Wheel/Rail Load Environment Caused by Freight Car Suspension Dynamics", A Paper Presented at the 68th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1989.

[20] Kalay, Semih and Albert Reinschmidt. "An Overview of the Wheel/Rail Load Environment Caused by Freight Car Suspension Dynamics", A Paper Presented at the 68th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1989.

[21] *An Estimation of the Investment In Track and Structures Needed to Handle 286,000 lb. Rail Cars*, prepared for the American Short Line and Regional Railroad Association, ZETA-TECH Associates, 2000.

[22] *Stress* is a load (or force) divided by the area over which it is applied. It can be measured in pounds per square inch (psi). The bending or vertical stress applied at the rail is related to the wheel load and the contact area. The maximum allowable stress in the subgrade varies with soil characteristics and environmental factors. The 20-psi value is a generalization. The actual subgrade bearing capacity at which significant permanent deformation occurs varies with local conditions.

[23] Thus, the assumption of an elastic foundation is only approximately correct (Ahlf, 1988). However, it will allow simulation of the effects of various wheel loads on different qualities and types of track structures.

[24] In the case of railroad track, elasticity is the ability of the track structure to return to its original *surface* condition (e.g., smoothness or vertical evenness over distance) and *alignment* (the position of the track in the horizontal plane). However, even with proper elastic responses under ideal conditions, some small permanent deformation typically occurs in track materials from applied heavy carloads. Consequently, over time (and under heavy loads) the subgrade and even the ballast will gradually compress or consolidate.

[25] Hay, William W. *Railroad Engineering*, 2nd Edition, John Wiley & Sons, 1982. Page 258.

[26] At the time these guidelines were developed, AREMA was the American Railway Engineering Association. In this study, all references to this association use the current name. A key reference for the deflection guideline of 0.25 inches is: Report of the Committee on Economics and Construction Maintenance, *Proceedings of the American Railway Engineering Association*, 1974.

[27] The source of the deflection guidelines shown Table 3.1 is: J.R. Lungdren, et al., *A simulation Model of Ballast Support and the Modulus of Track Elasticity*, Transportation Series Report 14, University of Illinois, 1970. The criteria are shown in Figure 15.8 of: William W. Hay. *Railroad Engineering*, 2nd Edition, John Wiley & Sons, 1982.

[28] Moment of inertia is measured in inches to the fourth power.

[29] Hay, William W. *Railroad Engineering*, 2nd Edition, John Wiley & Sons, 1982. Page 264.

[30] Hay (1982, p. 248) defines modulus as "the amount of load in pounds on a one-inch length of rail required to compress the track by one inch."

[31] Ahlf, Robert E. "The Behavior of Railroad Track and the Economical Practices of Its Maintenance and Upgrading," in *Roadbed and Rails: Fundamentals, Maintenance, and Economics*, Institute of Railroad Engineering, 1988.

[32] An individual crosstie's load distribution potential is limited by the size of the tie and the spacing interval. An individual crosstie's load distribution potential is limited by the size of the tie and the spacing interval. Thus, larger ties (e.g., 7' x 9' x 8' 6") are preferred. The load on the rail is essentially distributed across an area of the crosstie by the tie plate. Thus, larger, heavier tie plates can improve the track structure and extend the lives of the crossties (by avoiding plate cutting or crushing).

[33] This example is developed from: Hay (1982, Figure 22.7, p. 448). The theoretical values reflect AREA data and assume: 132 lb rail and a track modulus of 2,000 (meaning an average track support value).

[34] Following Hay (1982), track modulus is computed in Figure 1 as: 131 * (Tie Bearing Area / 2) / s where the Tie Bearing Area is equal to .67* l * b, where l and b are the length and width of the cross tie, respectively.

[35] Ahlf, Robert E. "The Behavior of Railroad Track and the Economical Practices of Its Maintenance and Upgrading," in *Roadbed and Rails: Fundamentals, Maintenance, and Economics*, Institute of Railroad Engineering, 1988.

[36] Ahlf, Robert E. "The Behavior of Railroad Track and the Economical Practices of Its Maintenance and Upgrading," in *Roadbed and Rails: Fundamentals, Maintenance, and Economics*, Institute of Railroad Engineering, 1988.

[37] Scenario 1 reflects 22" of ballast while scenarios 2 and 3 reflect 16 inches. Effective tie spacings are 21 inches for scenarios 1 and 2 and 29 inches for scenario 3.

[38] *An Estimation of the Investment In Track and Structures Needed to Handle 286,000 lb. Rail Cars*, Prepared for the American Short Line and Regional Railroad Association, ZETA-TECH Associates, 2000.

[39] The ultimate bearing capacities of fine-grained soils such as silt and clay are functions of their unconfined compressive strength.

[40] Alternatively, the maximum allowable pressure on soil may be 20 psi or more in arid regions.

[41] Excessive subgrade pressure can result in rapid (shear) failure or consolidation of soils. Unfortunately, consolidation is usually not uniform due to the various mixes and qualities of underlying subgrade. Differential consolidation, among other things, results in the need to surface the track structure periodically.

Appendix A

Washington State Heavy Axle Load Study: Technical Report

List of Exhibits

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Chapter One
Introduction

The problem: Freight-car axle weights are increasing

A transition to heavier rail cars has been underway in the United States for some time. In the 1970s, much of the branch-line network was restricted to gross car weights of 220,000 pounds, which allowed net loads of 70 to 80 tons. However, the need for effective use of 100-ton hopper cars resulted in branch-line capacity limits being raised to 263,000 pounds. Today, most Class I mainlines allow 286,000-pound cars with net loads of 110 to 115 tons. Some railroads operate 315,000-pound cars in designated mainline corridors. These 315-kip (315,000-pound) cars accommodate net loads of 125 tons.[5]

While the gross weights of freight cars have been increasing over time, the basic axle design has remained the same.[6] Most freight cars still have the same number of axles (four) and wheels (eight). Consequently, axle and wheel loads have been increasing with gross car weights (Table 1.1).

Table 1.1
Typical Freight Car Weights and Wheel Loads

Common Net Car Loads (Tons)	Gross Car Weights (Pounds)	Wheel Loads (Pounds)
80	220,000	27,500
100	263,000	32,875
111	286,000	35,750
125	315,000	39,375

The axle and wheel loads are important because the weight of the car is transmitted to the rails and underlying track structure through them. The term *heavy axle load* has been used to describe cars with gross loads of 263,000 pounds or greater. Admittedly, it is a relative term. In this study, heavy axle load (HAL) is used to describe cars that are heavier than the 263,000-pound cars that have been used on branch lines and short-line railroads for many years.

Why are heavier freight cars a problem for short-line railroads and branch lines?

Short-line railroads interchange most of their traffic with Class I carriers. In order to remain viable in the future, these small railroads need to handle heavier cars.

HAL cars pose special problems for short-line railroads, as well as for some Class I branch lines. In general, heavy cars exacerbate four branch-line problem areas:[7]

- Light rails (e.g., rail weighing 90-pounds per yard or less)
- Thin ballast sections (e.g., less than a foot of ballast under the ties)
- Deferred tie maintenance
- Old bridges

Much of the branch-line network in Washington State is built with 90-pound rail or lighter. In hard financial times, some of these lines may have suffered from deferred maintenance. According to survey data, many short-line miles have thin ballast sections and a substantial number of defective crossties.[8]

Most branch-line bridges were built decades ago in an era of relatively light car weights. Many of these older bridges are timber structures that have been exposed to the elements for more than 100 years. In the Pacific region, short-line railroads own approximately .47 bridges per mile.[9]

Today, some short-line railroads are handling HAL cars by moving at very slow speeds (e.g., 5 mph or less). This is a short-run response to a long-run problem. Higher speeds increase the dynamic effects of wheel loads. Car wheels tend to move about on the rail surface in response to irregularities. Moreover, the jointed rails that are present in many branch-line tracks increase car motion and amplify periodic oscillations. On the positive side, higher speeds offer many efficiency benefits and may be necessary for long-term survival.

It is doubtful that short-line railroads can make the transition to HAL cars simply by operating at very slow speeds. The opportunity cost of the freight cars, crews, and other productive assets is too great for these types of operations.

Why are Class I railroads using heavier freight cars?

Larger rail cars offer many cost savings to Class I railroads because of their higher net weight-to-tare weight ratios.[10] Higher net-to-tare weight ratios reduce the annual car miles required to haul a given tonnage, and thus reduce car ownership costs per ton. A higher net-to-tare ratio also reduces the number of axles required to haul an equivalent train weight, and thus reduces train resistance and fuel cost per ton-mile.[11] Finally, larger cars used in unit train service reduce labor costs per ton-mile because a given train length is comprised of more revenue tons.

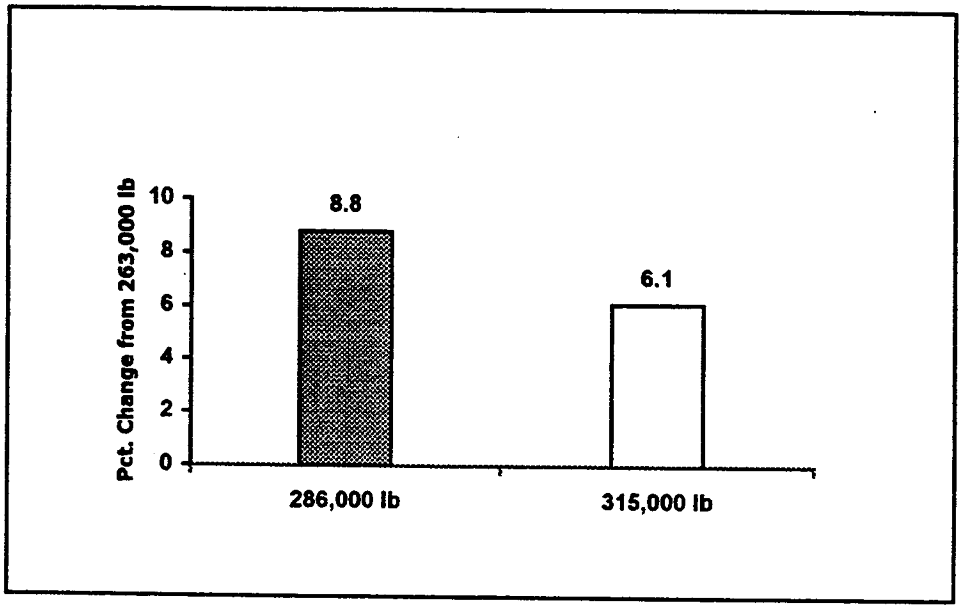
The Association of American Railroads (AAR) has conducted a variety of HAL tests during the last 15 years at its test track in Pueblo, Colorado. The results of these tests have been used in economic studies to forecast the potential benefits of HAL cars. For example, Figure 1.1 shows the projected benefits of using HAL cars with premium suspensions in mainline service.[12] In this figure, the costs of HAL cars are compared to the costs of 263,000-pound cars. However, only train and operational costs are shown in the comparison. Track and bridge costs are discussed separately.

As the chart shows, the operational cost savings for Class I railroads are greatest for the 286,000-pound car. In essence, the railroads' own studies show that they will realize greater cost savings from 286,000-pound cars than from 315,000-pound cars.

The sources of the operational cost savings are shown in Figure 1.2.[13] Because crew costs are fixed for a given train, 315,000-pound cars result in the greatest cost savings per ton-mile (15 percent versus 10 percent for the 286,000-pound car). However, the lighter 286-pound cars result in greater fuel savings (7 percent versus 4 percent). Moreover, 286,000-pound cars in unit train service result in more efficient locomotive utilization. Thus, locomotive ownership and maintenance costs per ton-mile are lowest for the 286,000-pound cars.

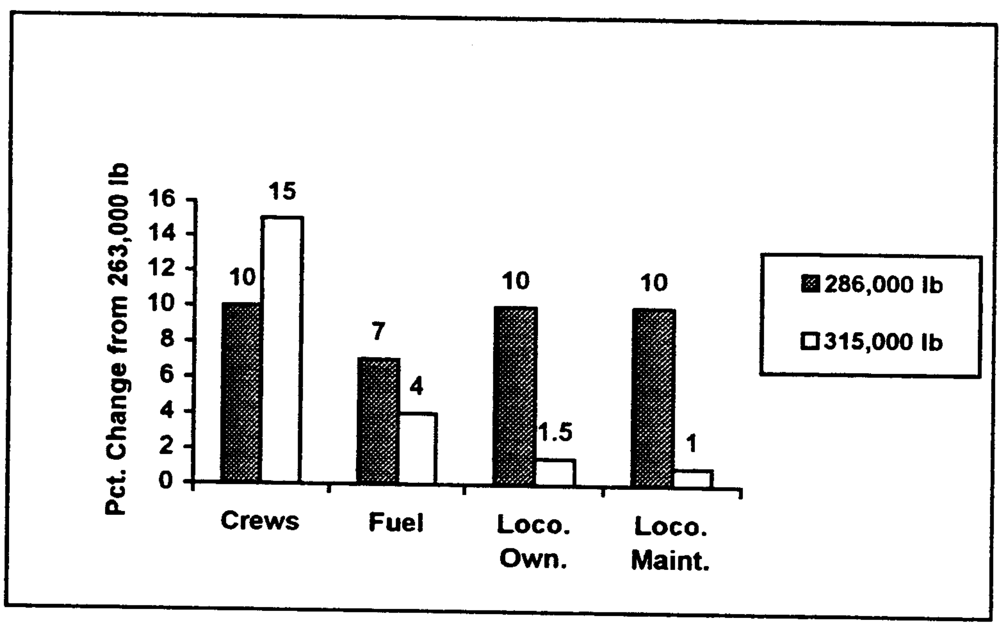
As Figure 1.3 shows, the car cost savings are mixed.[14] The 286,000-pound car yields the greatest car ownership cost savings because of its lower initial investment cost. However, the 315,000-pound car yields the greatest maintenance cost savings per ton-mile because of its greater payload capacity.

Figure 1.1
Projected Operational Cost Savings from HAL Cars in Comparison to 263,000-pound Cars



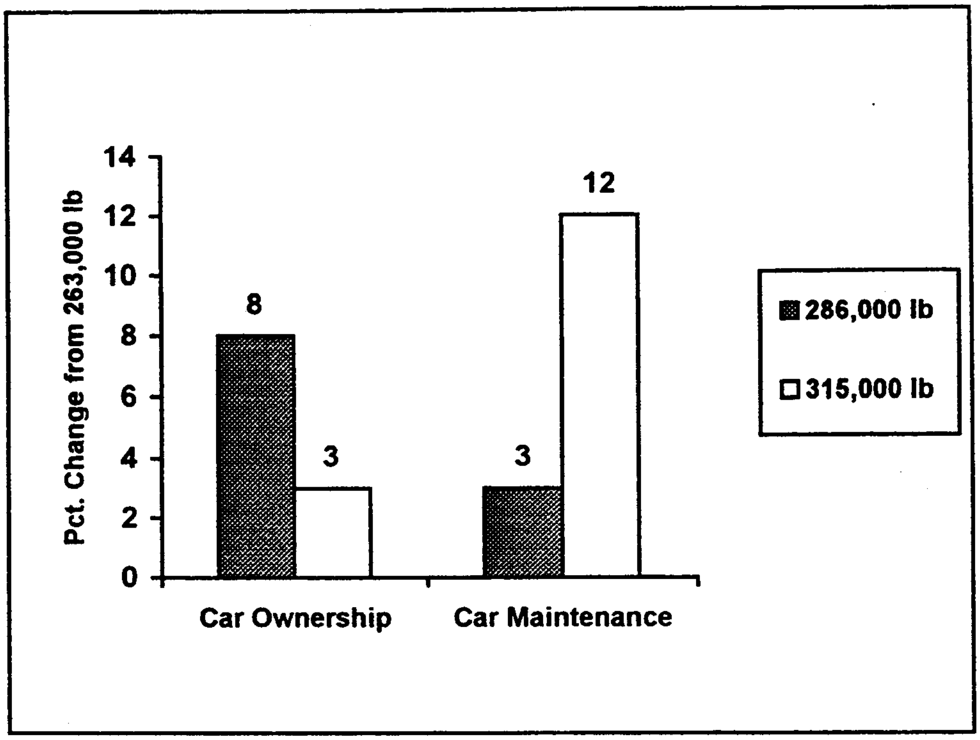
The 286,000-pound Car Offers the Greatest Potential Cost Savings

Figure 1.2
Labor, Fuel, and Locomotive Cost Savings from HAL Cars in Comparison to 263,000-pound Cars



The 286,000-pound Car Offers the Greatest Fuel and Equipment Cost Savings

Figure 1.3
Projected Car Cost Savings for HAL Cars in Comparison to 263,000-pound Cars



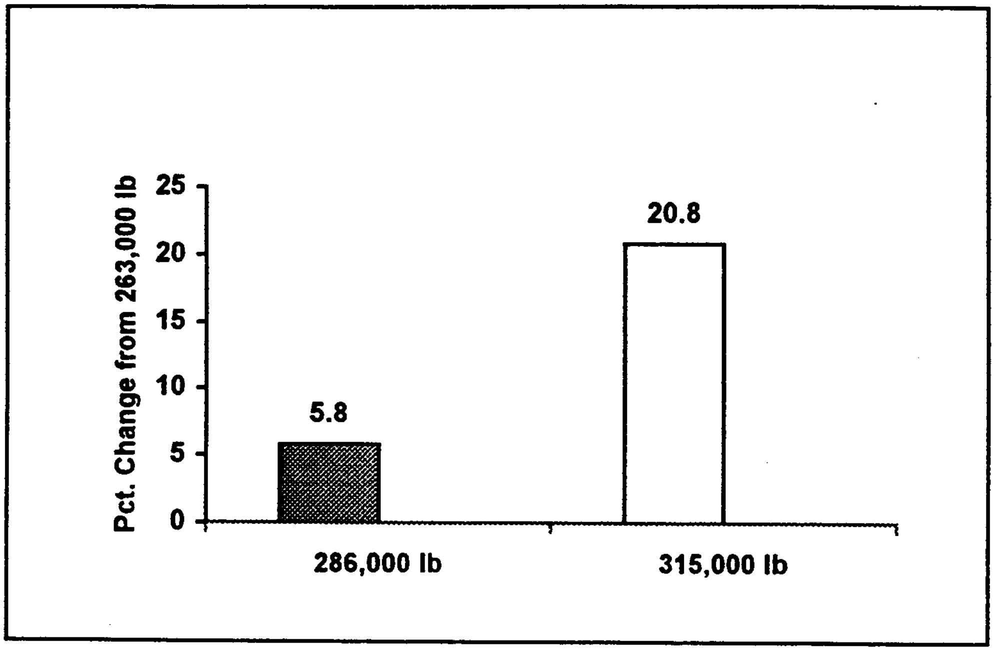
The 286,000-pound Car Offers the Greatest Car Ownership Cost Savings

What are the effects of HAL cars on mainlines?

The economic benefits of larger cars must be weighed against the increased equipment and track maintenance costs that will result from their use. In the AAR's simulations, mainline track and bridge costs are projected to increase by 20.8 percent if 315,000-pound cars are used instead of 263,000-pound cars (Figure 1.4).[15] In comparison, the use of 286,000-pound cars is expected to increase track and bridge costs by only 5.8 percent.

Much of the projected cost increase is attributable to reduced bridge life and increased structural repair of bridge members. In the simulations, bridge costs are projected to increase by 12.3 percent for the 286,000-pound car, as compared to 73 percent for the 315,000-pound car.

Figure 1.4
Incremental Track & Bridge Costs of HAL Cars in Comparison to 263,000-pound Cars



HAL Cars Would Significantly Increase Mainline Track and Bridge Costs

What research questions are addressed by this study?

The AAR has generated a library of HAL track tests and economic studies. However, these studies reflect movements over mainline tracks with heavy rails. The studies are **not** applicable to branch lines with light rail or deferred track maintenance.

This study addresses four important research questions concerning the use of 286,000-pound freight cars:

- How will existing branch-line track in Washington State perform under heavier axle loads?
- How do speed, rail weight, tie maintenance, and ballast depth affect track performance under heavier axle loads?
- What track designs are needed to ensure long-run performance under heavier axle loads?
- What track rehabilitation or upgrading costs are necessary?

The remainder of the technical report is organized as follows:

- A brief review of previous HAL studies is presented
- The analytical techniques and data sources used in this study are described
- The physical performance of rail under heavy axle loads is evaluated for various combinations of tie conditions and ballast depths
- Based on these evaluations, light-rail sections are identified that will not perform adequately
- Based on survey data and detailed track charts, the miles of rail line in the state of Washington that need upgrading are estimated
- The rail weights and track conditions to which inadequate lines should be upgraded are identified
- The statewide cost of upgrading inadequate lines is estimated
- The implications of not making the investments are discussed

Chapter Two
Review of Studies and Research Objectives

What information is available from previous studies?

Findings of the AAR Panel on 100-ton cars

In 1981, an AAR panel of distinguished railroad engineers compared the expected impacts of 263,000-pound cars on well-maintained tangent track with 132-pound continuous welded rail to the expected impacts of 220,000-pound cars on the same track. The panel concluded that rail life would be 1.5 to 2.1 times greater, while tie and ballast lives would be 1.0 to 1.4 times greater under the lighter 80-ton car loads. The panel's report also noted that the impacts of heavier 100-ton cars would be much greater on light rail and poorly maintained track. However, these effects were not quantified.

Findings of the Ahlf Study of 100-ton cars

Robert Ahlf (1980) developed an economic-engineering model of maintenance of way and structure (MW&S) costs using reported Class I railroad maintenance expenses and workload measures (such as gross ton miles).[16] He classified each MW&S cost element into one of three categories: 1) fixed costs; 2) costs that vary in relation to the mechanical actions of the track under load; and 3) costs that vary with rail life. The costs of ballast, ties, and track surfacing events were included in Category 2 (costs that vary with track mechanical action). Rail deflection was used as an indicator of the mechanical actions of the track under different axle loads and track support conditions

Ahlf concluded that:

- 39 percent of MW&S costs vary with track mechanical action
- 17 percent of MW&S costs vary with rail life
- Industry deployment of 100-ton cars will reduce rail service life by about 50% – a finding that is consistent with the maximum impact projected by the AAR panel

Ahlf's estimates of incremental MW&S cost are summarized in Table 1.2.[17] In the same study, he compared the incremental track cost to the potential operational cost savings of 100-ton cars. He used data from nine unit train movements to estimate locomotive fuel, maintenance, and ownership costs savings. Moreover, he used freight car prices and expected service lives to develop annualized car ownership cost estimates. His overall conclusion was that railroads would incur a net economic penalty of .061 cents per ton-mile from the use of 100-ton versus 80-ton cars.[18]

Table 1.2
Estimates of the Incremental Costs of 100-Ton Vs. 80-Ton Cars

Track Quality	Incremental Cost per Ton-Mile (1980 Dollars)	Percentage Increase in Ton-Mile Cost
Poor	$0.135	31.80%
Average	$0.107	39.20%
Good	$0.091	48.30%
Source: Ahlf, 1980		

AAR studies of HAL forces and track dynamics

The AAR has conducted a series of heavy axle load tests during the last 15 years. These tests have focused on rail/wheel interactions, the effects of heavy axle loads on track structure, and the effects of freight car suspension systems on vertical and lateral forces and dynamic loads.

The results of the AAR studies of cars with premium suspensions were summarized in Figures 1.1 through 1.4. In actuality, this particular study was the culmination of a series of HAL studies over many years. In general, the AAR's tests have shown that freight cars experience dynamic loads in excess of 1.8 times the static load at high speeds due to a wide variety of track irregularities. The most damaging loads are produced by "harmonically excited vehicles" especially when "excited by periodic, parallel 39' low joints."[19] In those cases, the AAR found that the peak vertical wheel load could be as high as 3 to 5 times the static wheel load.[20]

The AAR's findings on dynamic wheel loads are especially relevant to this study. Many branch lines are built with jointed 39-foot rails. In this track design, the wheel loads are transferred from one rail to another via joint bars. After years of use, the rail ends may become battered and areas of relatively low track support may develop under the joints. Even usable light rail sections may need to be welded into longer sections to dampen the peak dynamic wheel loads generated from HAL cars.

Findings of Iowa Department of Transportation

In 1998, the Iowa Department of Transportation (IDOT) analyzed the potential impacts of 286,000-pound cars on the state's branch-line network. IDOT made several assumptions regarding the track structure necessary for long-term performance:

- Replace all rail weighing less than 112-pounds per yard
- Replace all turnouts whenever rail is replaced

- Replace enough crossties so that 75 percent of the ties in a rail section are non-defective
- Add enough ballast so that at least 6 inches of clean ballast underlies the crossties

Using these minimum standards, IDOT concluded that approximately 1400 miles of rail line need some rehabilitation work. The unit costs used in the Iowa analysis are shown in Table 1.3. As the table shows, IDOT estimates that it will cost $169,000 per mile to replace rails and turnouts, and approximately $262,000 per mile to completely upgrade a track section. The overall cost estimate includes the costs of crossties, ballast, tie plates, and other track materials.

Table 1.3
Track Upgrading Costs Used in the Iowa Department of Transportation Study

Cost Item	Cost per Mile
Rails and Turnouts	$ 169,156
Ties	$ 58,657
Ballast	$ 24,604
Miscellaneous	$ 9,968
Total	$ 262,385

All 1400 miles of branch line analyzed in the Iowa study do not require complete rehabilitation. Thus, the average rehabilitation cost per mile is approximately $177,000. For the entire state, IDOT estimates that $250 million in rehabilitation costs are needed to accommodate 286,000-pound cars. Bridge rehabilitation costs are not reflected in this estimate.

Findings of Grain Short-Line Railroad Study

Martens (1999) conducted a survey of "grain" short-line railroads in the United States. He found that:

- 38 percent of the route miles of the responding railroads will not be able to adequately handle 286,000-pound cars even at slow speeds
- 18 percent of the grain shippers served by the responding railroads will be affected by track closings due to 286,000-pound cars
- Approximately $119,000 per mile in track upgrading costs will be necessary to keep all route miles open
- Another $52,000 per mile will be needed in bridge upgrading costs

On average, Martens estimates that it will cost approximately $267,000 to rehabilitate a bridge. His total upgrading cost estimates for grain short-line railroads are $170,000 per mile, including bridge rehabilitation costs.

Findings of American Short-Line and Regional Railroad Association Study

In 2000, the American Short-Line and Regional Railroad Association (ASLRRA) commissioned a HAL study by ZETA-TECH. In this study, ZETA-TECH surveyed 46 short-line and regional railroads. Collectively, these 46 railroads operate more than 4,700 miles of track and comprise approximately 10 percent of the industry's track miles.

In the survey, ZETA-TECH collected detailed information on track and bridge conditions, annual traffic volumes, and operating speeds. They also developed a series of "logic matrices" to determine when various combinations of rail weights, tie conditions, and ballast depths and qualities are adequate to handle 286,000-lb cars. Using the survey information in conjunction with the logic matrices, ZETA-TECH estimated the rails, ties, ballast, and bridges that need to be repaired or replaced for the sample of railroads. Then, they expanded the results of the survey to the short-line industry.

The rehabilitation costs used in the American Short-Line and Regional Railroad Association study are shown in Table 1.4.[21] As shown in the table, the cost to completely upgrade a mile of track, including turnouts, is approximately $516,000.

Table 1.4
Track Upgrading Unit Costs per mile used in the American Short Line and Regional Railroad Association Study

Component	Unit	Cost
Rail	Track-mile	$345,966
Ties	Tie	$39
Ballast (2")	Track-mile	$2,000
Surfacing	Track-mile	$5,636
Turnout	Turnout	$41,605
Complete replacement	**Track-mile**	**$516,066**

All 4700 miles analyzed in the ALSRRA study do not require complete rehabilitation. The average rehabilitation cost per mile is approximately $137,000, exclusive of bridge costs (Table 1.5). Expanding their results to the industry, ZETA-TECH estimates that approximately $6.86 billion in improvements are needed for short-line railroads to accommodate HAL cars.

Table 1.5
Average Rehabilitation Cost per mile used in the American Short Line and Regional Railroad Association Study

Component	Required Investment per Mile
Rail	$75,106
Ties	$16,372
Ballast/Surfacing	$2,657
Turnouts	$7,882
Bridges	$35,236
Total	**$137,253**

What information is added by this study?

The studies reviewed in this section make important contributions to our collective understanding of HAL effects. Many of the same studies will be referred to again later in the chapter. Although important, these studies don't answer all of the questions regarding long-term use of HAL cars on branch lines. Nor, do they address the specific research objectives of this study.

In summary, the limitations of previous studies are:

- They don't describe conditions in Washington State or provide information that can be used directly in policy evaluation
- They don't model track performance explicitly; therefore important conclusions are grounded in engineering judgment or proprietary models, which are not easily transferable to other states or circumstances

In this study, the performance of track under heavy axle loads is analyzed using publicly available models. As a result, the findings can be verified or replicated by others. Before discussing track performance, some background concepts in track analysis are introduced in Chapter Three.

Chapter Three
Performance of Track Under Heavy Axle Loads

How does track respond to heavy axle loads?

A stationary 263,000-pound car generates a *static* wheel load of 32,875 pounds. If the steel wheel and rail are relatively new, the contact area is about one-quarter of an inch. In this case, the static load on the rail is 131,500 pounds per square inch (psi). Ideally, the track structure must distribute this wheel load to the subgrade so that the maximum stress does not exceed 20 psi.[22] To complicate matters, dynamic loads from a freight car in motion are much greater than static wheel loads.

A 286,000-pound car applies a static wheel load to the rail that is nearly 9 percent greater than the 263,000-pound car, and 30 percent greater than the 220,000-pound car. These increases may seem insignificant for mainlines. However, they may have long-term consequences for branch-line track.

What functions are performed by track components?

In terms of load distribution, the rails, ties, tie plates, and ballast function as a system. The rail functions as a continuous beam (or at least continuous over a section) and spreads a wheel load longitudinally to several crossties via the tie plates.[23] The crossties help distribute the load laterally and provide for a more uniform vertical distribution to the ballast section below. The ballast further distributes the load to the subgrade resulting in lower and more uniform pressure on underlying (natural) roadbed soils.

How is track performance measured?

Resilience or elasticity is the ability of a material to return to its original shape or position after an applied load has been removed.[24] The amount of elastic compression and rebound of a track structure is called *deflection*.

Vertical deflection (measured in inches) is the best single indicator of track strength, life, and quality (Hay, 1982). Excessive deflection results in differential movement and wear of track components. Tie and ballast actions can result in ballast abrasion, which leads to many additional problems, including poor drainage. Moreover, excessive deflection can result in permanent deformation of subgrade soils. As noted by Hay (1982), the "up-and-down pumping action of the track as wheel loads are repetitively applied and released is a prime source of track deterioration."[25]

What is excessive deflection?

Some track deflection is unavoidable and essential; but what is too much? Over the years, several agencies and individuals have developed guidelines for maximum deflection including: the American Railway Engineering and Maintenance Association (AREMA, 1974)[26] and Lundgren (1970).[27] These guidelines are summarized in Table 3.1.

The AREMA guidelines recommend a maximum deflection of 0.25 inches for heavy track with reasonably firm subgrade. The limit of desirable deflection for track of light construction is .36 inches. According to the guidelines, track that deflects .40 inches or more will deteriorate quickly under heavy axle loads.

Table 3.1
Vertical Track Deflection Ranges and Expected Track Behavior

Maximum Deflection (Inches)	Track Behavior
0.00 to 0.13	Deflection range for track that will last indefinitely
0.13 to 0.25	Normal maximum desirable deflection for heavy track to give requisite combination of flexibility and stiffness
0.36	Limit of desirable deflection for track of light construction (≤ 100 lb)
0.40 or greater	Weak or poorly maintained track that will deteriorate quickly

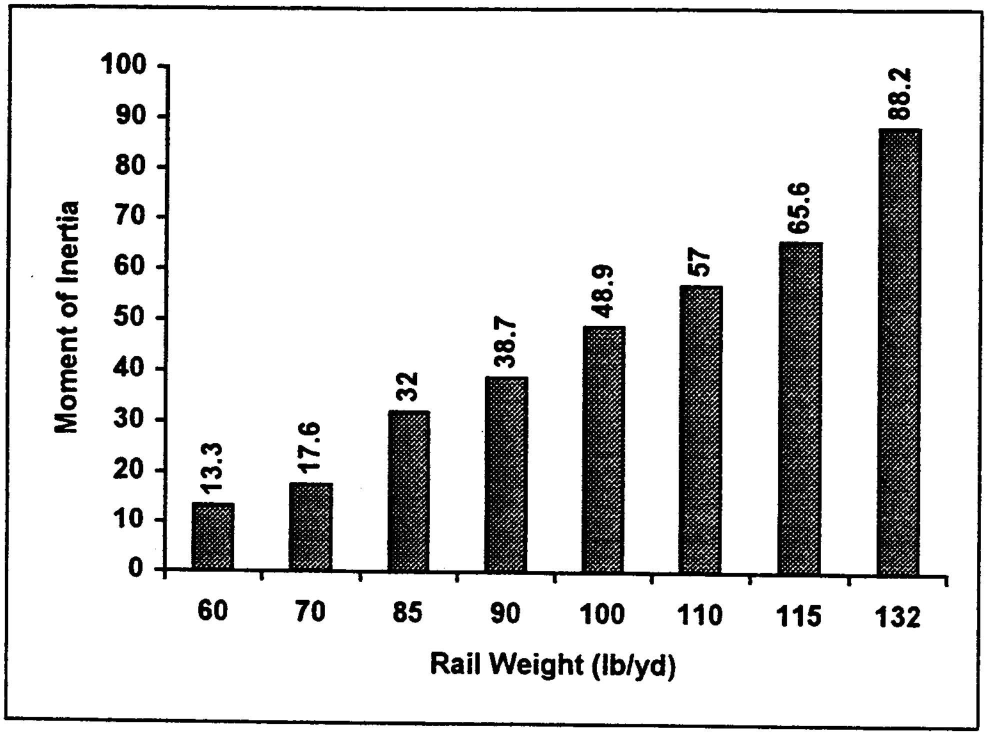
What is the role of rail weight in track performance?

Rail weight is measured pounds per yard. Heavier rail increases the stiffness of the track structure and reduces deflection. Moreover, heavier rail contributes to overall track stability and acts as a "bridge" over areas of weak track support (e.g., sections of failed cross ties or poor ballast and subgrade). Because of its greater bending resistance, heavier rail increases the lives of crossties.

Rail stiffness or bending resistance increases with the *moment of inertia* (I). In steel beams of similar cross section (such as T rails), the moment of inertia is proportional to the cross-section area and varies with the square of the weight (Hay, 1982).[28] Intuitively, its importance is as an indicator of rail stiffness.

Figure 3.1 shows an approximate relationship between rail weight and stiffness for common rail sections. As the chart shows, replacing 85-lb rail with 115-pound rail doubles rail stiffness. Replacing 70-lb rail with 115-lb rail increases rail stiffness 3.7 times.

Figure 3.1
Relationship between
Rail Weight and Stiffness



Replacing 85-pound Rail with 115-pound Rail Doubles Rail Stiffness

Can HAL cars be accommodated simply by laying heavier rails?

No! The support beneath the rails is a critical factor. William Hay, author of a classic text in railroad engineering, writes:[29]

> *A common correction for poor track has been to lay new and heavier rail. The money might often be better spent in increasing the strength and stiffness of the rail support. One might as well try to stabilize a sinking building by adding another story to it.*

The track structure is truly a system. The quality of one component affects overall performance, as well as the life expectancies of other components. Simply increasing the weight of rail (which creates greater stiffness or bending resistance) will not necessarily compensate for other poor components (e.g., ties or ballast).

How does the support beneath the rails affect track performance?

The track structure must simultaneously satisfy requirements for stiffness (i.e., resistance to deflection) and flexibility. Track quality is measured by a composite term called *modulus*, which is an overall measure of support underneath the rail.[30] Because modulus simultaneously reflects track stiffness and flexibility, very high values represent a structure that is too stiff.

Track modulus is affected by ballast depth and quality and by subgrade characteristics. However, modulus also is impacted by crosstie characteristics and conditions. Generalized track modulus values are shown in Table 3.2.

Table 3.2
Generalized Track Modulus Values

Very Low	500 psi
Poor	1,000 psi
Average	2,000 psi
Good	3,000 psi
Very Hard	5,000 psi
Source: Ahlf (1988)[31]	

Later in this chapter, a track deflection equation is presented. Modulus and moment of inertia are two important factors in the equation. The equation can be used to illustrate the comparative benefits of rail stiffness and support beneath the rails.

As shown in Figure 3.1, replacing 100-pound rail with 132-pound rail will increase moment of inertia by about 80 percent. However, placing the heavier rail in an average track (e.g., modulus of 2,000 psi) will decrease deflection by only 14 percent. In comparison, an 80 percent increase in modulus— from 2,000 to 3,600 psi—will decrease deflection by about 36 percent.

How does tie maintenance affect track support?

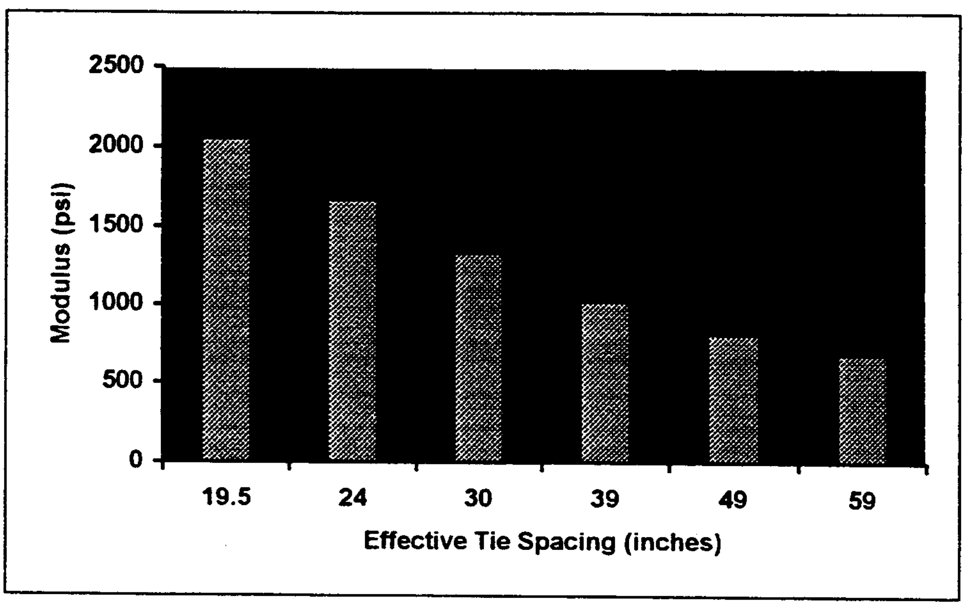
A wheel load may be distributed to more than seven crossties in a conventional track structure, with the center tie carrying between 15 percent and 40 percent of the load (Zarembski, 1992.)[32] The dimensions and qualities of the crossties and the effective tie spacing affect the load distribution per tie within a section of track.

In general, tie spacing refers to the center-to-center distance between adjacent ties. Design spacing may range from 19.5 inches on high-traffic main lines to 24 inches on low-traffic branch lines (Simmons-Boardman, 1985). However, *effective* tie spacing means the center-to-center distance between non-defective ("good") ties. Broken, split, rotting, or otherwise damaged crossties may not qualify as "effective ties" since their load distribution capabilities are diminished.

Fewer effective ties under a section of rail (and/or greater spacing between ties) mean that each good tie must assume a higher unit load. For example, each tie in a track section with an effective spacing of 19.5 inches would bear approximately 40% of the axle load distribution. In comparison, the same type of tie located in a track section with an effective spacing of 28" would bear approximately 60% of the load distribution.[33]

Track modulus is affected by ballast depth and quality, subgrade characteristics, and crosstie conditions and spacing. Figure 3.2 illustrates the relationship between track modulus and effective tie spacing (*s*) for otherwise "average track."[34]

Figure 3.2
Effect of Tie Spacing on Track Support



Effective Tie Spacing has a Major Effect on Overall Track Support

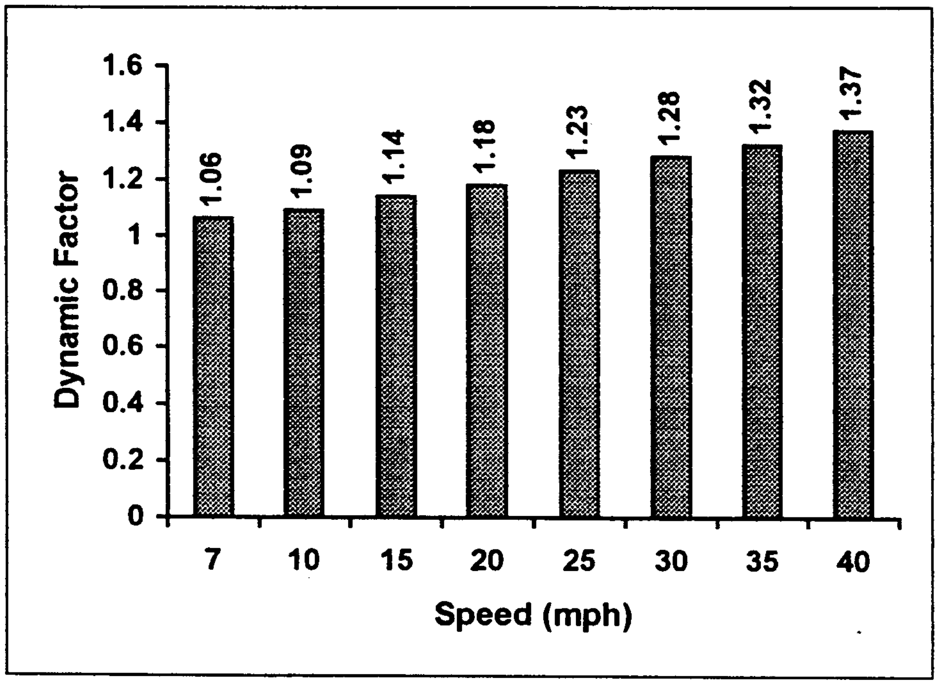
An effective tie spacing of 19.5 inches (a mainline standard) results in approximately 24 non-defective ties per 39-foot rail section, or 3,200 ties per mile. An effective tie spacing of 29 inches corresponds to approximately two-thirds non-defective ties per rail section. An effective tie spacing of 39 inches corresponds to approximately half non-defective ties. Finally, an effective spacing of 59 inches results in only one-third of the non-defective ties typically found in a mainline section.

How does speed affect applied loads and track performance?

Speed is an important variable in analyzing the effects of heavy axle loads. It is accounted for in the deflection model through a dynamic factor. The dynamic factor is a multiplier that increases the stress of a static wheel load to account for the effects of roll, slip, vibration, unequal load distribution, and related forces of motion.

Figure 3.3 illustrates dynamic factors for train speeds of 40 mph or less on average track. As the chart shows, the dynamic factor increases from 1.09 at 10 mph to 1.37 at 40 mph.

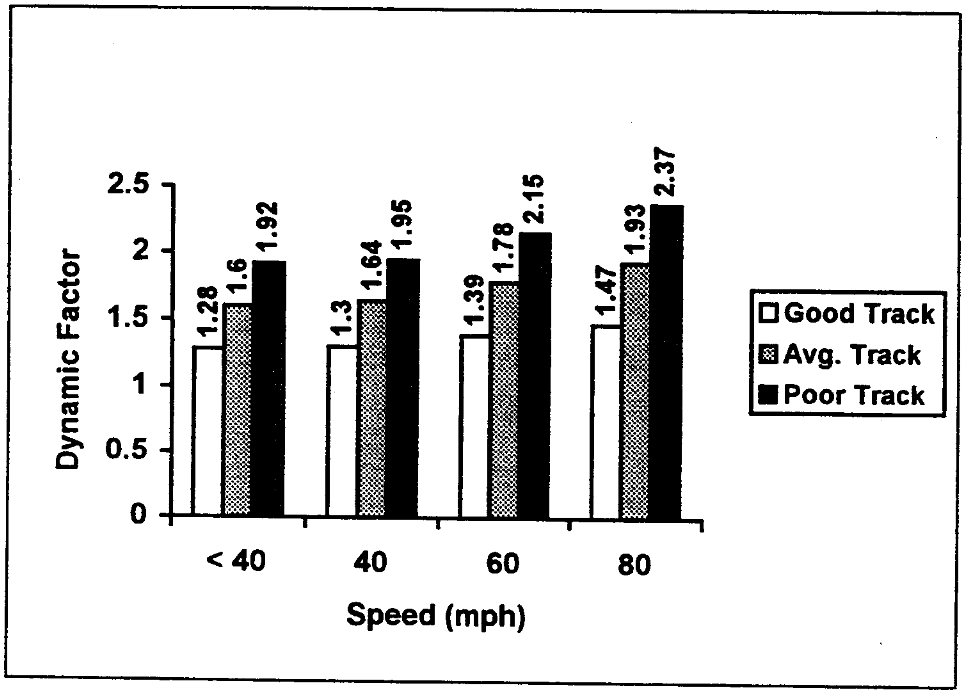
Figure 3.3
General Effects of Speed on Dynamic Load Factor



On Average Track, the Dynamic Effects of Wheel Loads are 1.37 Times Greater than the Static Load at 40 mph

Although the factors shown in Figure 3.3 are useful, they don't distinguish among types of track. As noted earlier, AAR has concluded that freight cars sometimes experience dynamic loads in excess of 1.8 times the static load at 40 mph due to a wide variety of track irregularities. Figure 3.4 shows other dynamic factors frequently used in track analysis.[35] These factors are a function of speed and track quality. As the chart shows, the dynamic factor ranges from 1.28 on good track at speeds of less than 40 mph to 2.37 on poor track at speeds of 80 mph. As the chart also illustrates, the "poor track" dynamic factor is 1.5 times greater than the "good track" dynamic factor at speeds of less than 40 mph.

Figure 3.4
Dynamic Wheel Load Factors as a Function of Speed and Track Quality



At 40 mph, the Dynamic Wheel Load on Poor Track is 1.95 Times the Static Wheel Load

How is track performance modeled in this study?

In this study, track performance is simulated using a track deflection equation originally developed by the American Railway Engineering Association Committee on Track Stresses, based on the work of A. N. Talbot. The Talbot equations have been widely used in track analysis. They are documented in Hay (1982). Ahlf (1988) illustrates the use of a similar stress model in track analysis.[36] According to Hay, Talbot=s equations are Acomprehensive@ and Aproduce results very close to those observed in the field.@

The primary track deflection equation used in this study is shown in Equation 1.

Equation 1

$$Y_o = \frac{P}{\sqrt[4]{64\ EIu^3}}$$

Where:

Y_o = Vertical deflection (in inches)
P = Dynamic wheel load (in pounds)
E = Elasticity of rail steel (30,000,000 psi)
I = Moment of inertia of steel rail (Figure 3.1)
U = Track modulus

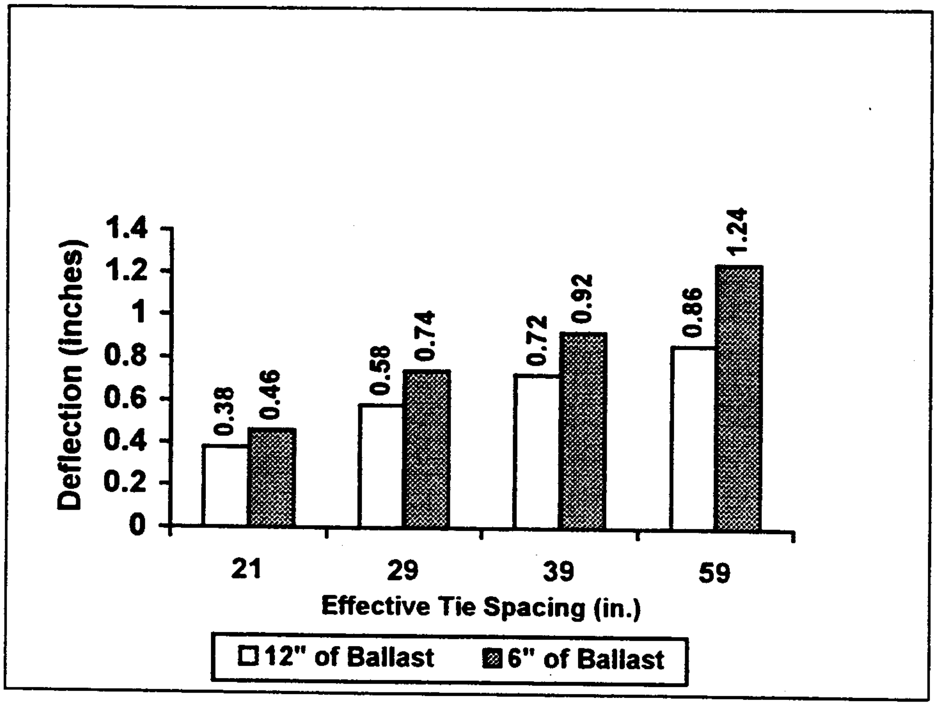
As shown in Equation 1, deflection (Y_o) is directly related to the dynamic wheel load (P) and inversely related to track support. Specifically, deflection is inversely related to the three-quarters power of track modulus (u). Furthermore, deflection is inversely related to the 4th root of rail stiffness as measured by moment of inertia (I) and the modulus of elasticity of rail steel (E).

How do light-rail sections perform under heavy axle loads?

In this study, track performance is simulated for 90-pound and 70-pound rail using Equation 1. Effective tie spacing, ballast depth, and track modulus are varied for each weight class to illustrate the effects of track support and maintenance standards on deflection. Operating speeds of less than 40 mph are assumed.

Figure 3.5 illustrates variations in track deflection for a 90-pound rail section and two ballast depths: 12 inches and 6 inches. Although the track deflections exceed recommended maximums in all cases, deflections are less than one-half inch with good tie maintenance (e.g., an effective spacing of 21 inches). However, with one-third defective ties and only six inches of ballast, the hypothetical track section experiences deflection of nearly three-fourths of an inch. Moreover, a 90-pound rail section with two-thirds defective ties and six inches of ballast can deflect as much as 1.24 inches.

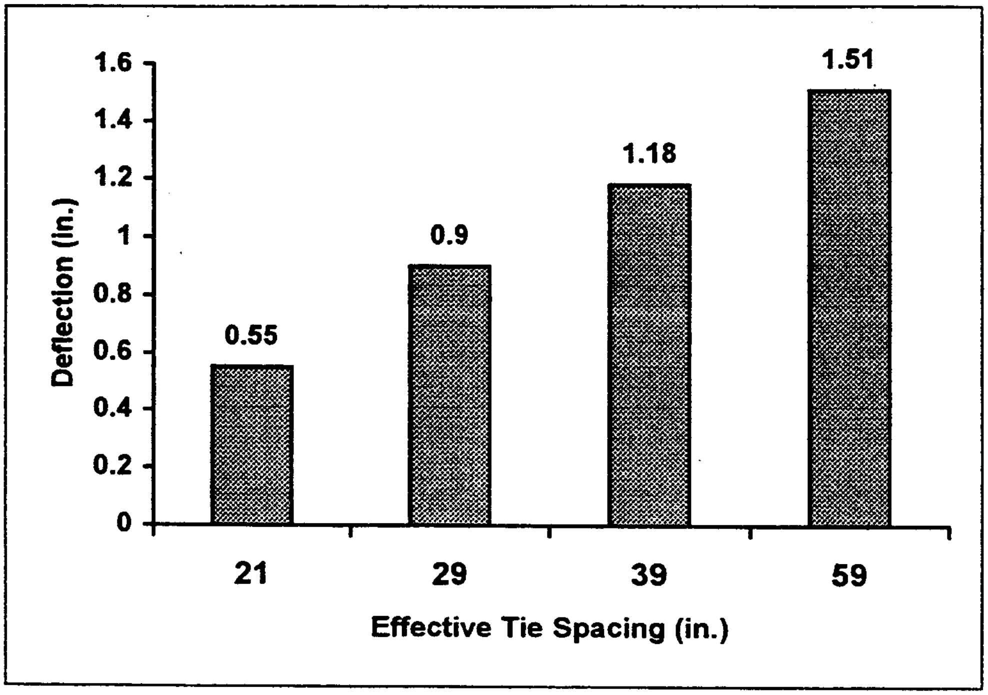
Figure 3.5
Predicted Track Deflection for 90-pound Rail with Varying Tie Spacing and Ballast Depths



With 90-lb Rail, Track Deflections under 286,000-pound Car Wheel Loads Exceed .5 Inches with One-third Defective Ties and .7 Inches with 50% Defective Ties at Speeds < 40 mph

Figure 3.6 shows deflections for track with 70-pound rail and six inches of ballast. As the chart shows, high deflections of .55 inches could occur on this track even with good tie maintenance. Excessive deflection of .9 inches occurs with only one-third defective ties. With 50 percent bad ties and six inches of ballast, this track structure could deflect as much as 1.18 inches. Finally, with two-thirds bad ties, the simulated deflections exceed 1.5 inches.

Figure 3.6
Predicted Track Deflection of 70-pound Rail with 6-inches of Ballast



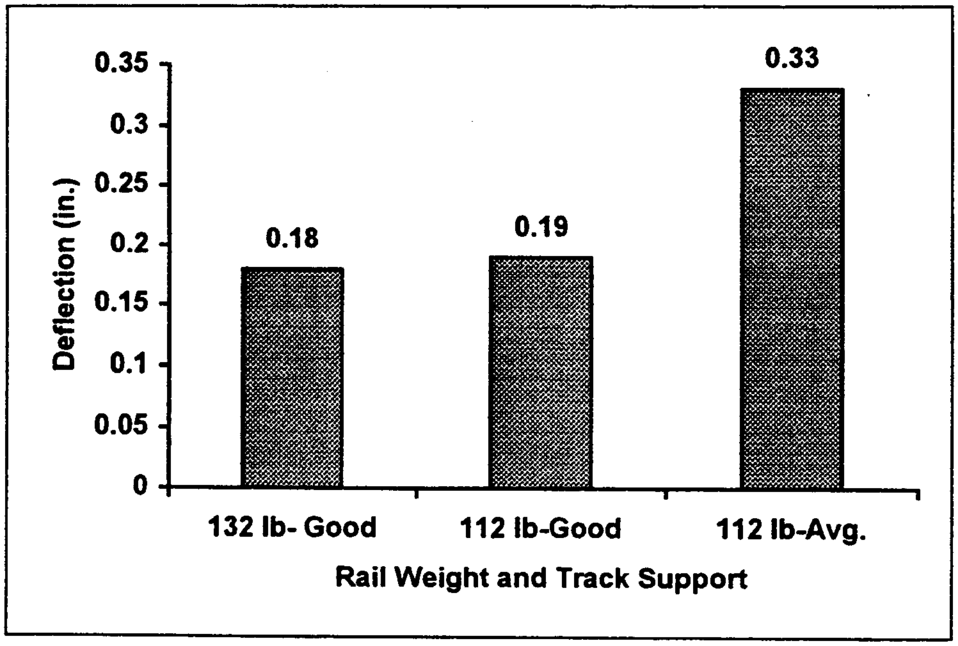
With 70-lb Rail, Thin Ballast, and 50% Defective Ties, Track Deflects 1.18 Inches Under 286,000-lb Car Wheel Loads at Speeds < 40 mph

A final scenario examines track performance under slow speed operations. Equation 1 predicts a maximum deflection of .27 inches for a 286,000-pound car moving over a 90-pound rail section with 12 inches of ballast and good tie maintenance at 13 mph.

How do heavier rail sections perform under heavy axle loads?

Three heavy-rail scenarios are analyzed using generalized track parameters: 132-pound rail with good track support; 112-pound rail with good track support; and 112-pound rail with average track support.[37] In each case, the effects of 286,000-pound cars moving at 40 mph are simulated. As Figure 3.7 shows, the expected track deflections are less than .25 inches for scenarios 1 and 2 and about one-third inch for scenario 3, which reflects 112-pound rail with 25 percent bad ties.

Figure 3.7
Predicted Deflection of Track with Heavy Rail Sections



Track with 112-pound Rail and Average Track Support Deflects Only .33 Inches Under 286,000-pound Car Wheel Loads at Speeds < 40 mph

Inferences and Conclusions

The deflection analysis has shown that overall track support and speed are important factors in light-density analysis, in addition to rail weight. With good tie maintenance, good ballast, and slow speed operations, 90-pound rail *may* perform satisfactorily under 286,000-pound carloads at slow speeds. However, deferred maintenance or higher speed operations will increase deflection to unacceptable levels. The simulations show that lighter rail (e.g., 70 pounds per yard) isn't likely to perform satisfactorily under HAL traffic. In comparison, 112-pound rail exhibits good track performance with average track support. These simulations suggest that it's desirable for railroads to upgrade track built with lighter rail (e.g., less than 90 pounds per yard). Moreover, when upgrading track, it's desirable to use heavier rail (e.g., 112-pound or 115-pound rail) instead of relaying track with used 90-pound rail.

These conclusions are consistent with the findings of other studies. IDOT concluded that light-rail sections with less than 112-pound rail should be upgraded. As shown in Tables 3.3 and 3.4, ZETA-TECH concluded that 90-pound rail is marginal, at best.[38] For example, ZETA-TECH recommends that 90-pound rail be replaced if the railroad desires to operate at speeds greater than 25 mph. Moreover, 90-pound rail should be replaced when traffic densities exceed 5 million gross tons. Finally, ZETA-TECH says that 90-pound rail is marginal for operating speeds of 25 mph or less, even at the lightest traffic densities.

Table 3.3
ZETA-TECH Evaluation of Rail Sections, by Traffic Density Ranges, for Operating Speed > 10 mph and ≤ 25 mph

Rail Weight	Traffic Density in Million Gross Tons		
	< 1	**1 – 5**	**5 – 10**
≥ 115 lb.	OK	OK	OK
100 – 114	OK	OK	Marginal
90 – 99	Marginal	Marginal	Replace rail
< 90 lb.	Replace	Replace	Replace rail

Table 3.4
ZETA-TECH Evaluation of Rail Sections, by Traffic Density Ranges, for Operating Speed > 25 mph

Rail Weight	Traffic Density in Million Gross Tons		
	< 1	**1 – 5**	**5 – 10**
≥ 115 lb.	OK	OK	OK
100 – 114	OK	Marginal	Marginal
90 - 99	Replace	Replace	Replace
< 90 lb.	Replace	Replace	Replace rail

Chapter Four
Track Rehabilitation Needs

The following conclusions were drawn from the track performance analysis and review of studies in Chapter Three:

- All track built with less than 90-pound rail should be upgraded
- Unless a track has excellent support and tie maintenance, 90-pound rail sections should be upgraded so that branch lines can be operated at cost-effective speeds (e.g., at least 25 mph)
- Jointed 90-pound rail that remains in service should be welded into longer sections to dampen dynamic effects and provide for more continuous support

How many miles of branch-line track need to be upgraded?

To answer this question, a questionnaire was distributed to short-line railroads in Washington. The mail survey was followed up with a telephone survey. A review of track charts and previous rail-line benefit cost studies was conducted. BNSF aided in the analysis of Class I branch lines by providing detailed track charts and other information.

From this combination of data sources, a list of line segments was identified in Washington State that may need upgrading. Table 4.1 lists the short-line railroad segments. Altogether, these segments comprise 384 miles of rail line. Table 4.2 shows the miles of BNSF branch line that may need upgrading. As shown in the table, 98 miles of BNSF rail line in Washington State are built with 85-pound rail or lighter. Another 167 miles are built with 90-pound jointed rail.

Table 4.1
Summary of Short Line Railroad Segments in Washington State Needing Rehabilitation

Railroad or Segment	Carrier	Rail Weights (lb per yard)	General Condition of Ties/Ballast/Subgrade	Miles
Schrag-Bassett Jct	CBRW	66, 72	Fair/Poor	12
Moses Lake-Bassett Jct	CBRW	60, 65, 80	Poor	15
Tri-Cities Railroad	TCRY	90	Fair/poor	7
Meeker-Southern		70	Not Available	4
Toppenish-White Swan	TWSR	90	Fair/Poor	19
City of Tacoma	TRMW	85 or less	Fair/Poor	54
Pend Oreille	POVA	75, 90	Fair/Good	16
Shelton-Elma	PSAP	90	Fair	24
PSAP: Scattered 72-lb	PSAP	72	Fair	5
Lewis & Clark	LINC	66	Fair	29
Walla Walla-Dayton	BLMR	56, 75, 80, 85	Fair	39
Hooper Jct-Colfax	PLRR	60, 75, 90	Poor	21
Colfax-Moscow	PLRR	56, 90	Poor	26
Winona-Thornton	PLRR	75	Poor	27
Coulee City-Cheney	PRCC	85, 90	Fair/Poor	40
Columbia Cascade	CSCD	65, 90	Fair	46

Table 4.2
Miles of BNSF Branch Line in Washington State with Light Rail

Rail Weight	Miles	Percent of BNSF Branch-Line Miles
68	11	1.9
77	2	0.3
85	85	14.6
90	167	28.6

How much will it cost per mile to upgrade these lines?

The cost to upgrade a rail line is very dependent upon its unique circumstances. Without detailed field studies, only generalized cost estimates can be developed. The estimates presented in this chapter are based on conversations with vendors (suppliers) and short-line railroads. The cost estimates reflect 4th quarter 2000 price quotes.

New heavy continuously welded rail generally costs over $500 per ton plus $150 in welding cost. Two types of used tangent rail are widely available on the market. Number 1 rail has 1/8 inch of headwear or less. Number 2 rail has 1/4 inch of headwear or less.

The price of used Number 2, 115-pound rail ranges from $450 to $500 per ton. This estimate doesn't include shop-welding cost, which is approximately $150 per ton. The price of used Number 1, 115-pound rail ranges from $475 to $525 a ton. Again, this figure doesn't include shop-welding cost, which is approximately $150 per ton. The price of used Number 2, 112-pound rail ranges from approximately $400 to $425 a ton. This price doesn't include shop-welding cost, which is approximately $150 per ton. Finally, the cost of used Number 1; 112-pound rail ranges from $425 to $450 a ton. Again, this figure doesn't include shop-welding cost, which is approximately $150 per ton.

Conceivably, these rails could be laid as jointed rail, which would require 270 joints per mile, at a cost of about $4,000 per mile. This figure includes the cost of two angle bars per joint, valued at $15 each. However, jointed rail may not provide the long-term performance needed under heavy axle loads. Therefore, this option isn't considered in the remainder of the analysis. Although purchasing new rail is an option, used rail is probably more cost-effective for the levels of traffic on these branch lines.

The lowest rail price quote was for curve-worn 132-pound rail. This rail is already continuously welded. It can be transposed and placed in tangent track. The estimated cost for this type of rail is $325 per ton.

These prices have been used to construct Tables 4.3 and 4.4, which show generalized rehabilitation cost estimates per mile. In Table 4.3, it is assumed that the line will be upgraded to 115-pound rail. In Table 4.4, it is assumed that the line will be upgraded using 132-pound curve-worn rails.

Table 4.3
Minimal Cost per mile
to upgrade to 115-pound Rail

Cost Item	Quantities	Unit Prices	Cost per Mile
Used 115# No. 1 rail	202.4	$625	$126,500
Tie Plates - 6,000 per mile	6,000.0	$4	$24,000
Rail Anchors - 6,000 per mile	6,000.0	$1	$6,000
Ties: 500 per mile	500.0	$41	$20,500
5/8 x 6 Truck Spikes - 50 kegs per mile	50.0	$65	$3,250
Labor - Rail relay @ $7.5 per foot	5,280.0	$7.50	$39,600
Field Welds - 8 per mile	8.0	$350	$2,800
Replace Crossings - 1 per mile	1.0	$3,000	$3,000
Ballast - 400 tons per mile	400.0	$16	$6,400
Surfacing per foot	5,280.0	$0.75	$3,960
Reclaim & reload rail and OTM - per mile	1.0	$3,000	$3,000
Labor & locomotive to distribute material	1.0	$2,000	$2,000
Subtotal: Direct Cost			$241,010
Contingencies: 10%			$24,101
Total per Mile			**$265,111**

Table 4.4
Minimal Cost per mile to upgrade to 132-pound Curve-Worn Rail

Cost Item	Quantities	Unit Price	Cost
Curve-worn 132-lb rail	232.3	$325	$75,504
Tie Plates - 6,000 per mile	6,000.0	$4	$24,000
Rail Anchors - 6,000 per mile	6,000.0	$1	$6,000
Ties: 500 per mile	500.0	$41	$20,500
5/8 x 6 Truck Spikes - 50 kegs per mile	50.0	$65	$3,250
Labor - Rail relay @ $7.5 per foot	5,280.0	$7.50	$39,600
Field Welds - 8 per mile	8.0	$350	$2,800
Replace Crossings - 1 per mile	1.0	$3,000	$3,000
Ballast - 400 tons per mile	400.0	$16	$6,400
Surfacing per foot	5,280.0	$0.75	$3,960
Reclaim & reload rail and OTM - per mile	1.0	$3,000	$3,000
Labor & locomotive to distribute material	1.0	$2,000	$2,000
Subtotal: Direct Cost			$190,014
Contingencies: 10%			$19,001
Total per Mile			**$209,015**

Without detailed field studies, it is not possible to develop accurate estimates of the salvage value of in-place branch-line assets. Typical salvage values range from $3,500 per mile to $12,000 per mile. A median value range of $4,000-$5,000 per mile is assumed for this study. These salvage values assume that the rails removed from branch lines are not suitable as relay rail for use in other rail lines.

In conclusion, the minimal cost to upgrade to115-pound rail is $265,000 per mile. After the salvage value of in-place assets is considered, the cost drops to $260,000 per mile. A lower upgrading cost may be possible by using curve-worn rail, in which case the estimated cost is about $205,000 per mile. Neither figure includes the costs of turnouts or bridges.

As shown in Chapter Two, Iowa Department of Transportation estimated that it would cost $262,000 per mile to upgrade branch lines in Iowa. The Iowa estimate includes the cost of turnouts. ZETA-TECH estimated a unit cost of approximately $42,000 per mile for turnouts.

The turnouts per mile for the lines shown in Tables 4.1 and 4.2 are unknown. However, if the ZETA-TECH estimate is used, the cost to upgrade a line to 115-pound rail including turnouts could exceed $300,000 per mile. At the lower end of the cost range, it may be possible to upgrade some track sections using curve-worn rail for about $250,000 per mile, including turnouts. Although there is uncertainty in these numbers, they provide some indication of the minimum costs needed to upgrade inadequate branch-line sections.

How much will it cost to rehabilitate branch lines in Washington?

Using the unit costs per mile discussed above, a range of statewide rehabilitation cost estimates is shown in Table 4.5. At the low end of the range, the estimated cost is $117 million. At the high end of the range, the estimated cost is approximately $141 million.

There are more than 1500 miles of branch line or short-line railroad in Washington State. Over 400 miles of these lines will need to be upgraded to handle HAL cars. It is assumed that the jointed 90-pound rail in BNSF branch lines has good overall support beneath the rails. These 167 miles of line are not reflected in the estimates shown in Table 4.5. Furthermore, the cost estimates do not include any bridge rehabilitation work, and some bridgework almost certainly will be needed. For these reasons, the estimates are presented as *minimum* rehabilitation costs.

Table 4.5
Range of Rehabilitation Cost Estimates for Branch Lines in Washington State

Miles of Short-Line Railroad	384
Miles of BNSF Branch Line	85
Total Miles Needing Rehabilitation	469
High Rehabilitation Cost per Mile	$ 300,000
High Statewide Cost Estimate	$140,700,000
Low Rehabilitation Cost per Mile	$ 250,000
Low Statewide Cost Estimate	$ 117,250,000

As mentioned earlier, the Iowa Department of Transportation estimated that $250 million would be needed for statewide rehabilitation of 1400 miles of rail line. The high statewide estimate of $141 million shown in Table 4.5 appears conservative in light of the Iowa and ZETA-TECH studies.

Caveats

Variability of prices

The rehabilitation costs used in this study are generalized estimates only. There are many sources of variability in the prices of rails, ties, and other track material (OTM). Rehabilitation costs may be affected by:

- Availability of used rail
- Current tie conditions (how many need to be replaced)
- The size of tie plates used in the line
- Quantities of spikes, anchors, and other track materials needed
- The salvage value of in-place track materials
- Transportation and labor costs

Consequently, the rehabilitation cost for any given branch line may be different from the general estimates shown in Tables 4.3 and 4.4.

Subgrade support

Soil support is an important factor in track performance. Very poor soils may cause long-term problems. Corrective subgrade work may be required in the worst cases. However, detailed records of the soil support beneath rail lines are not available publicly. Consequently, measures of soil support beneath branch-line tracks are not reflected directly in the track modulus estimates.

The structural support of a soil is sometimes referred to as *bearing capacity*.[39] The maximum allowable stress or pressure in the subgrade is usually measured in pounds per square inch. Typically, the bearing capacity of subgrade soils in moist regions of the United States is 9 psi, with values frequently ranging from 7 to 12 psi (Ahlf, 1989).[40] According to Ahlf (1989), a subgrade soil with a bearing value of 9 psi will typically result in permanent deformation of 0.20 inches per year (or less) under heavy wheel loads. Very weak soils may only have a support capacity of 5 psi, while very strong soils may have bearing capacities as high as 40 psi. As a point of reference, AREMA recommends a bearing capacity of 20 psi for purposes of modern railway design (AREMA, 1981).

Unfortunately, when many rail lines were originally constructed the subgrade material consisted of either the native material remaining after the cut or a fill material located adjacent to the roadbed. Only in recent times has it been standard practice to transport materials of desirable characteristics to the construction sites. Consequently, a major concern on many older branch lines is over stressing the existing subgrade. This concern is amplified by the increasing frequency of HAL cars on branch lines.[41]

In short, the impacts of heavy axle loads may be greatest in areas of weakest soil support. The cost of corrective subgrade work isn't reflected in the cost estimates shown in the report.

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Appendix B

Washington State Short Line Railroads Contacted in Study Surveys

Railroad	Carrier Code
Columbia Basin Railroad Company, Inc.	CBRW
Tri-Cities Railroad	TCRY
Toppenish, Simcoe & Western Railroad	TWSR
City of Tacoma	TRMW
Pend Oreille Valley Railroad	POVA
The Puget Sound & Pacific Railroad Company	PSAP
Lewis & Clark Railway Company	LINC
Blue Mountain Railroad	BLMR
Camas Prairie Railnet	CSP
Columbia & Cowlitz Railway Company	CLC
Palouse River & Coulee City	PCC
Columbia Cascade	CSCD
Mountain Vernon Terminal Ry. LLC	MVT
Meeker-Southern Railroad	

Appendix C

Shipper and Short Line Survey – Interview – Outline

HEAVY WEIGHT RAIL CAR SURVEY

INTERVIEWEE__________________________________

COMPANY_____________________________________

DATE______________ **BY**____________________

1. Are you aware of the car availability of 110 ton versus 100-ton rail cars—percentage of each?
2. Will your facilities accommodate 110 ton rail cars, and, if so, where?
3. Is the rate for a 110-ton rail car more, less, or the same as 100-ton rail car? Have you been using the 110-ton rail cars and loading them at 100 tons or less?
4. What is the rate structure and division with 110-ton rail cars versus 100-ton rail cars? Can you get the cars, and, if so, what size?
5. Will the move to 110-ton rail cars impact your finances or operations? Can you briefly explain?
6. What is your average traveling speed now? What is needed? Desired? For example what are the implications of 25 MPH versus 40 MPH?
7. Do you know the differences in rates for truck/barge versus 100-ton rail cars and 110-ton rail cars at the different locations/facilities on your line?
8. Does there appear to be some customer willingness to change modes—truck/barge to 110-ton cars? If there were, in fact, a lower rail car rate would there be a change to rail?
9. What are your thoughts on future possibilities for 110-ton rail cars—survival, inefficiencies, etc.? If you are using the 110-ton rail cars, but loading them at 100 tons or less, how long can you survive? Are there alternatives?
10. What would you like to tell us that we haven't asked?
11. OTHER?

Appendix D
Washington Short Line Railroad Survey Questionnaire

Dear {Railroad Manager}:

Thank your for attending the meeting in Spokane to discuss the Washington State heavy rail car study. At the meeting, we discussed some of the data that we will need to analyze the impacts and benefits of heavy cars. We hope that you will help us by providing information about existing track conditions and operations on your railroad system, by filling-out the enclosed survey forms.

The intent of the survey is to describe variations in track design and conditions on your railroad that would affect track performance under heavy axle loads. (For Class I railroads, the intent is describe conditions for your branch-line system only). In the survey forms, please enter the miles of road or route miles that fall under the category headings. For example, the first survey form asks for how many branch-line or short-line route miles are built with less than 70-pound rail and currently have less than six inches of ballast below the cross ties.

Thanks again for your participation and assistance. If you have questions regarding the purpose of the survey forms or definitions, please call Denver Tolliver at 701-231-7190 or contact him at Tolliver@badlands.nodak.edu.

Form 1- Miles of Road, by Rail Weight and Ballast Section **Railroad: ________**

Rail Weight (lb/yd)	Ballast Section Depths (Inches)				
	< 6	6-8	9-12	13-17	>= 18
< 70					
70-89					
90					
91-111					
112					
115					
131-132					

Form 2 - Miles of Road, by Crosstie Design **Railroad: ___________**

Rail Weight (lb/yd)	Percent Good Ties			
	> 85%	85%-65%	64%-45%	> 45%
< 70				
70-89				
90				
91-111				
112				
115				
131-132				

Form 3 -- Miles of Road, by Rail Type **Railroad: ____________**

Rail Weight (lb/yd)	Rail Type	
	Jointed	CWR
< 70		
70-89		
90		
91-111		
112		
115		
131-132		

Form 4 -- Miles of Road, by Track Class **Railroad: ____________**

Rail Weight (lb/yd)	FRA Track Class			
	1	2	3	4 or Higher
< 70				
70-89				
90				
91-111				
112				
115				
131-132				